Family counseling for moist parameterizations

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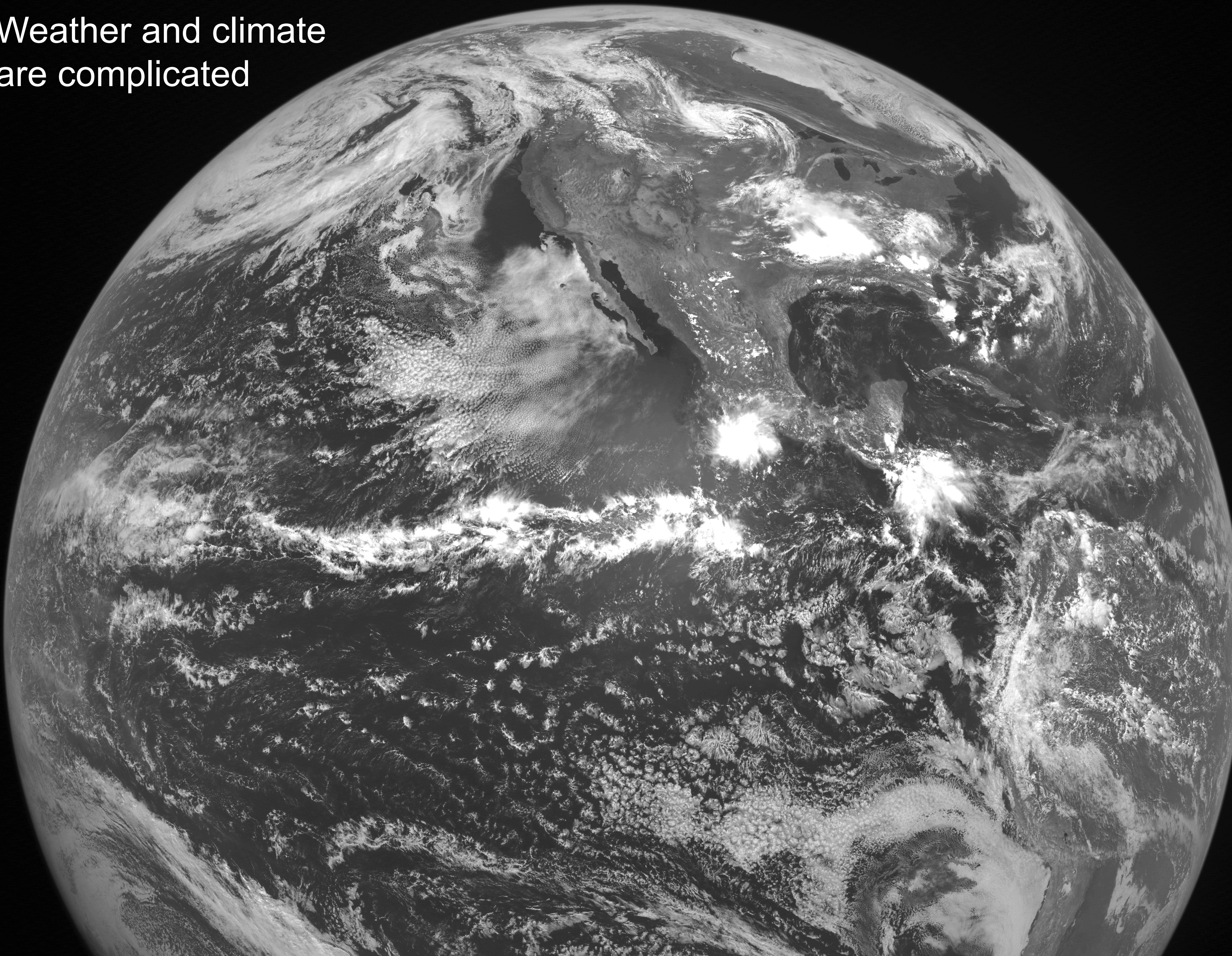
Weather and climate
are complicated



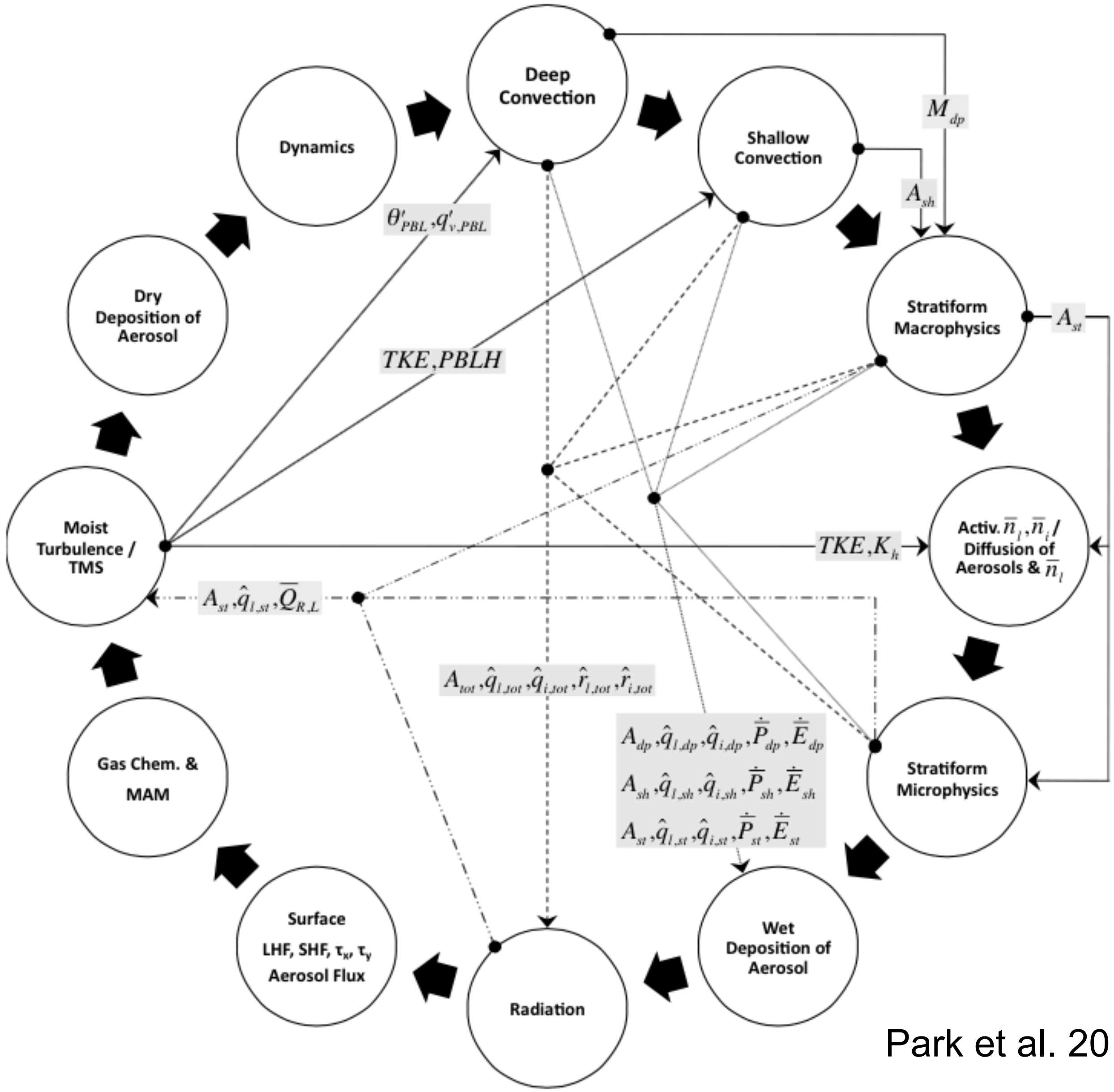

A GCM grid column

Another GCM grid column

Complexities of moist physics in large-scale models

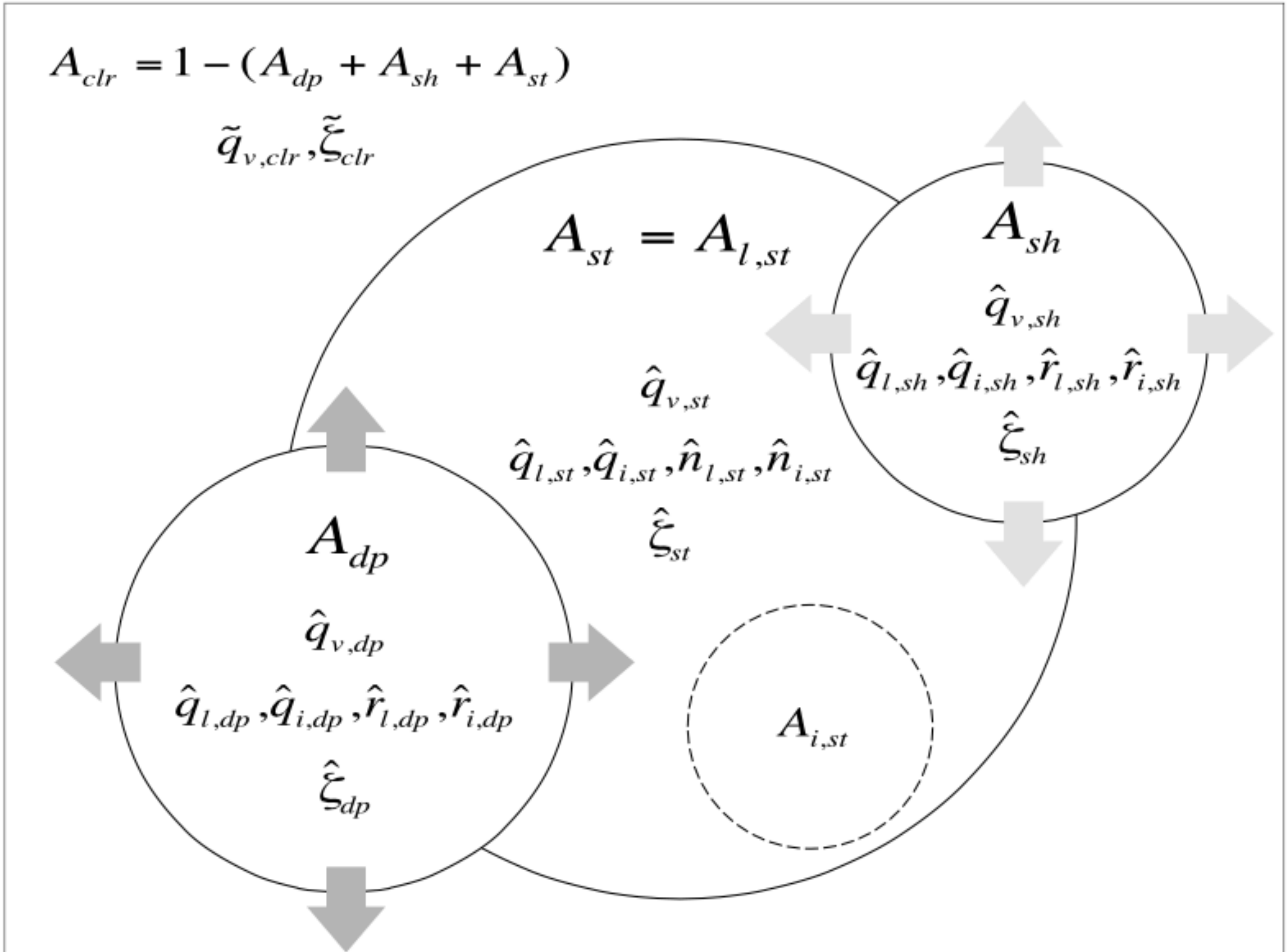
- Process complexity and interactions
- Multiscale in space and time
- Subgrid variability

The happy family of CAM5 physical parameterizations



Park et al. 2014 J Clim

…so many kinds of cloud to talk about



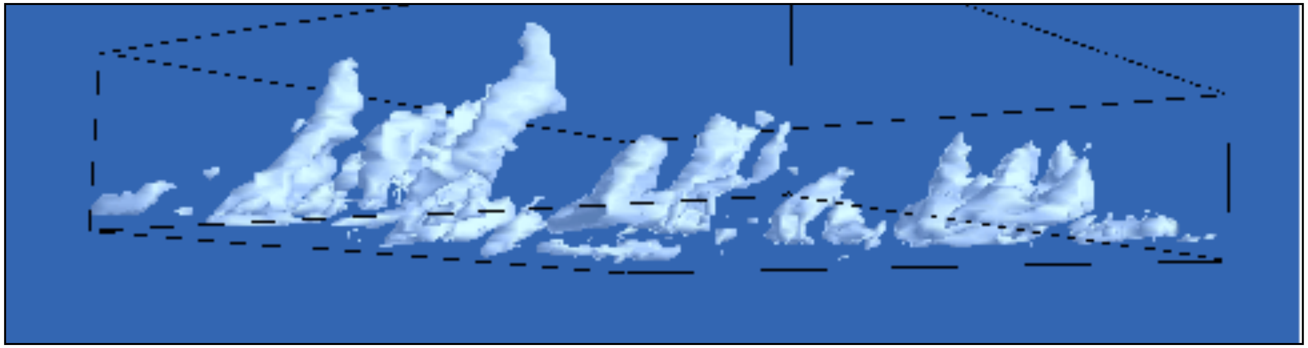
Park et al. 2014 J Clim

The challenge of simulating cloud processes

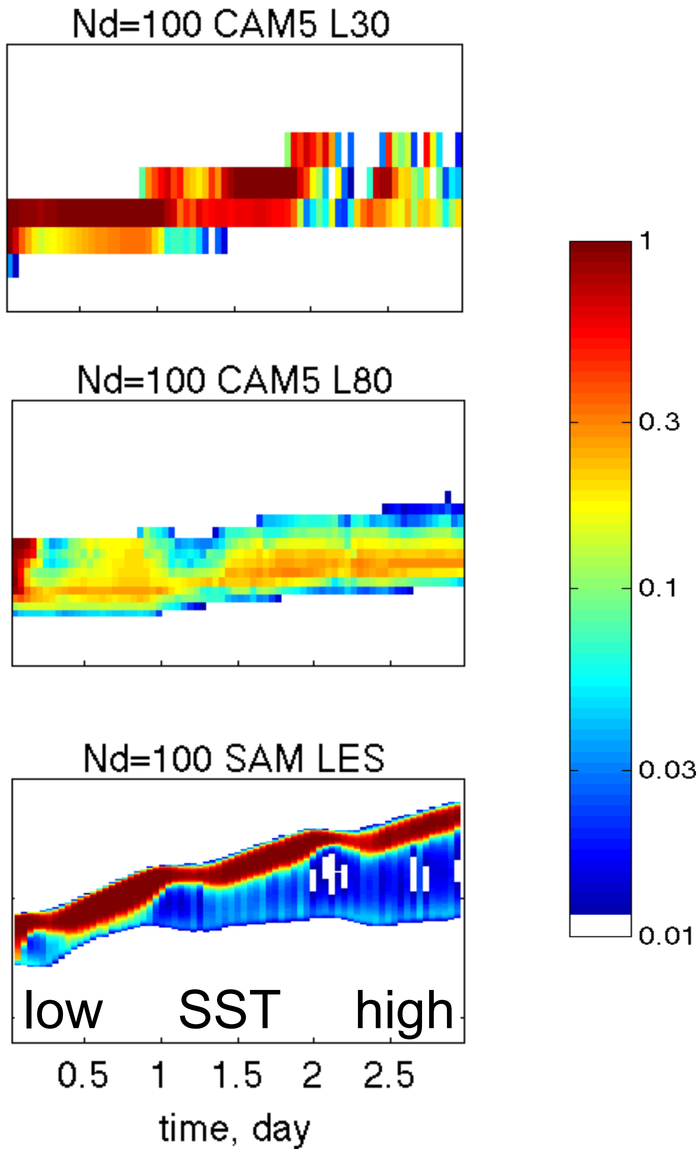
- Tight interactions between parameterizations: turbulence/convection, microphysics/precipitation, aerosols, surface properties, radiation - and resolved dynamics.
- Strong subgrid variability/covariability in space and time
- Discretization issues and parameterization interactions are as challenging as uncertainties within parameterizations.

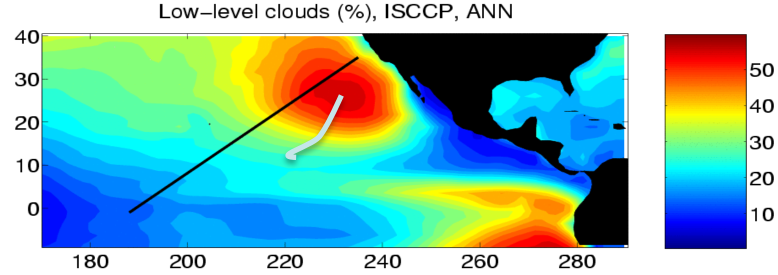
Comparison with large-eddy simulation

- In LES, most cloud dynamics are resolved
- Gridbox-mean temperature, moisture, condensate are adequate to describe the physical processes.
- Subgrid covariability (e. g. of LWC and w) not critical
- This conceptually simplifies the parameterization problem because a complex model of the subgrid structure of cloud is not needed.



SCM vertical resolution sensitivity



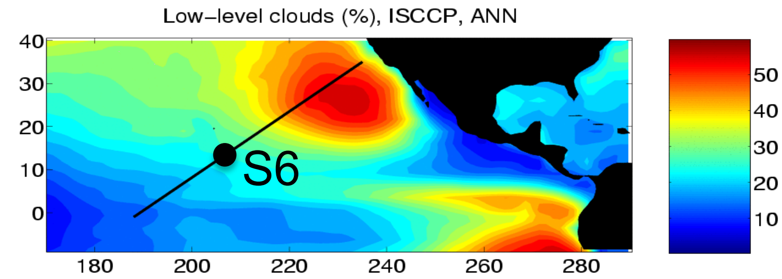


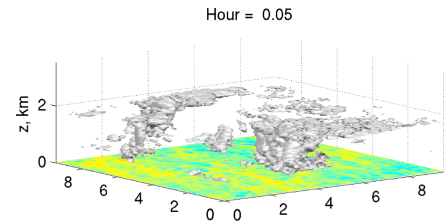
GASS Sc-Cu composite transition case (Sandu et al. 2011)

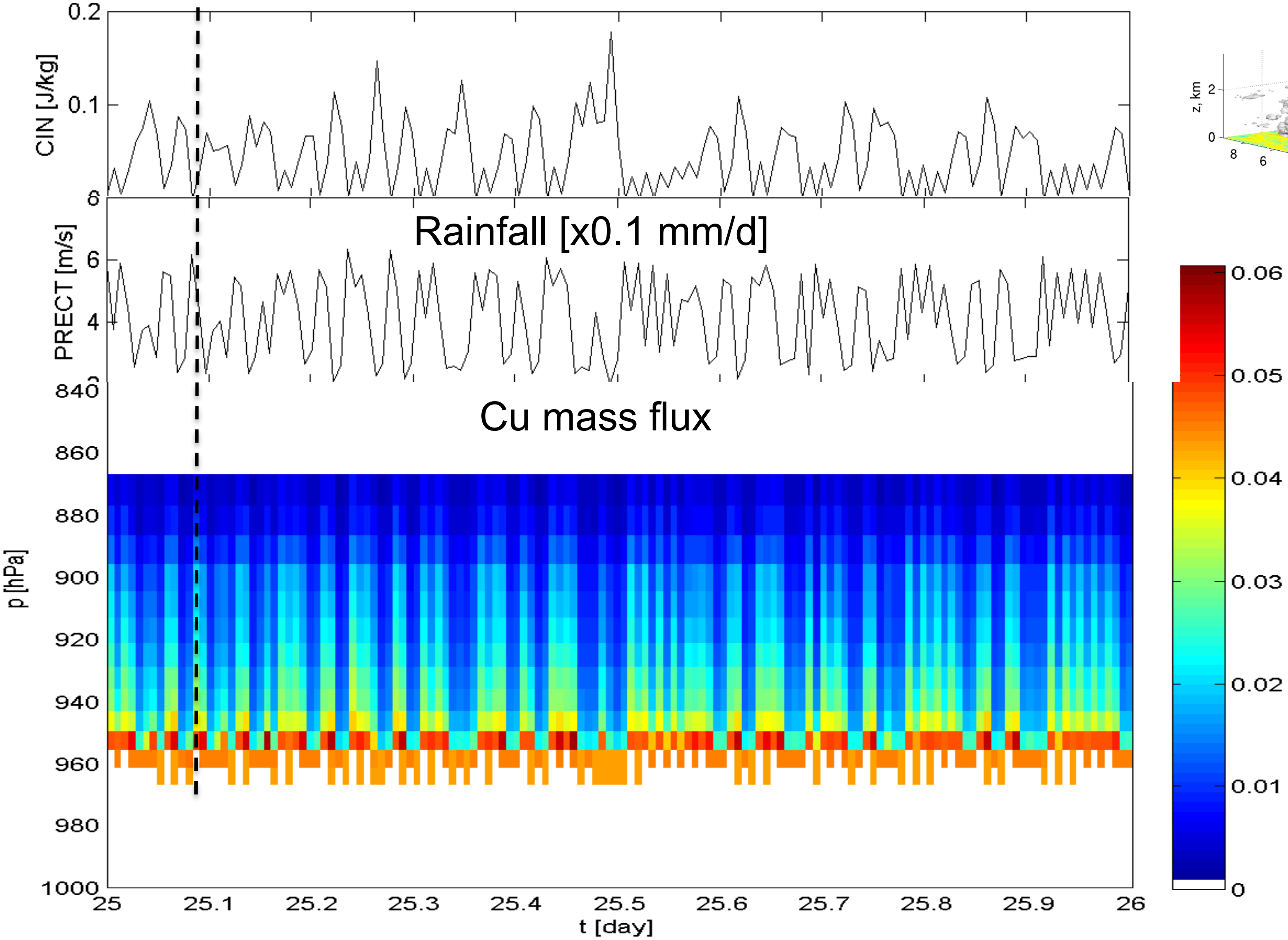
LES: 128x128x428, Δx = 35 m, Δz = 5 m, Δt ~ 1 s

SCAM5 artificial oscillations

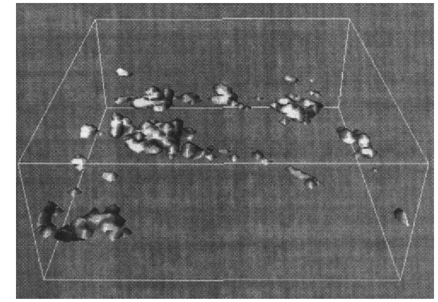
S6: Shallow Cu mass flux-precip-PBL feedbacks



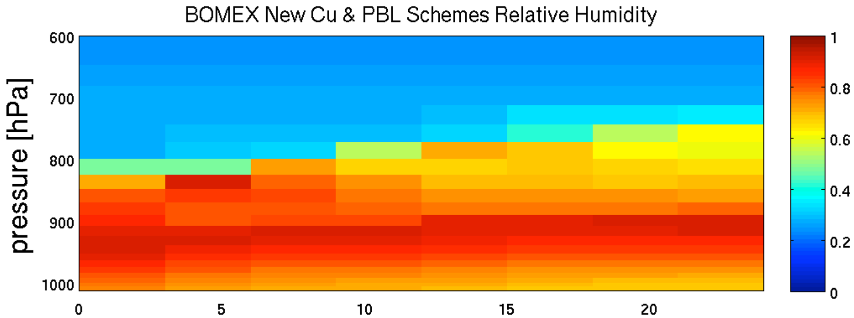


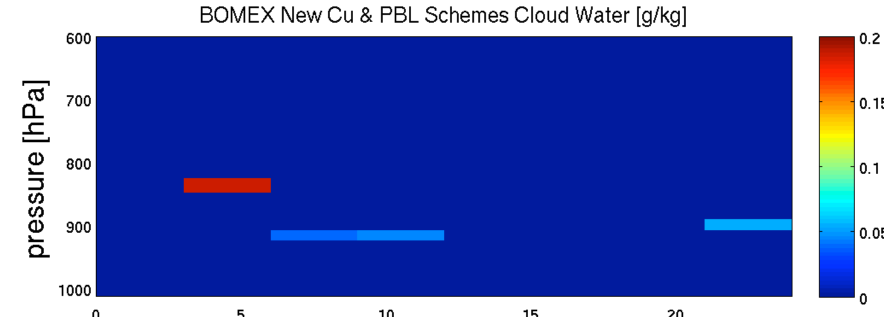


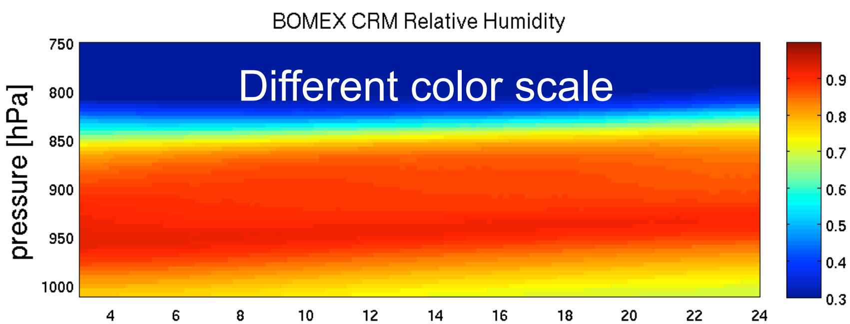
Empty clouds

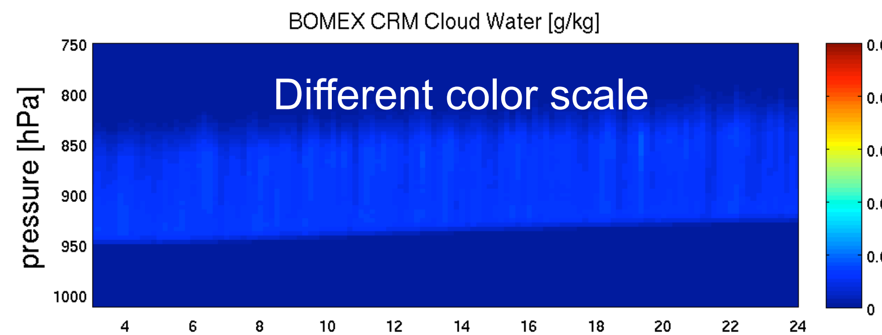


GFS-SCM on BOMEX nonprecipitating trade Cu case Siebesma et al. 2003

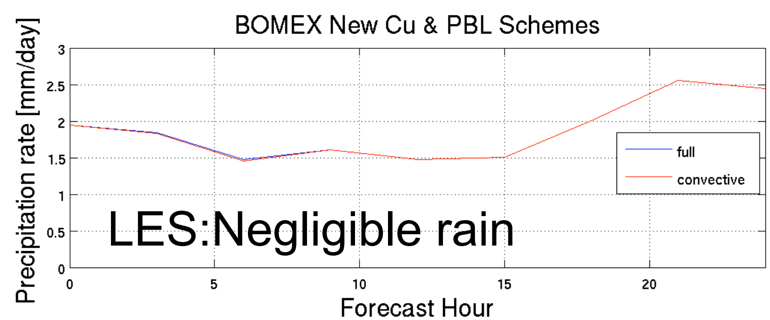








- Rains 2 mm/d with no cloud water at most Cu levels and timesteps.



Key considerations: A personal list

- Let the resolved scales do their work.
- Target the highest resolution, then step back.
- Parameterizations are cartoons of reality; take them with a grain of salt.
- Consistent level of process complexity across parameterizations
- Complexity should be added only to address a clear shortcoming in model simulations.
- Consistent representation of subgrid inhomogeneity and moist thermodynamics across parameterizations
- Algorithms appropriate for the vertical and time resolution
- Flexible, but clearly specified, interfaces between parameterizations.
- Well documented code, on-line descriptions, clear tuning parameters.
- Computational efficiency is not an afterthought!
- Testability: Parameterizations should improve global simulations of the process they were designed to fix, as well as a multivariate basket of skill scores.

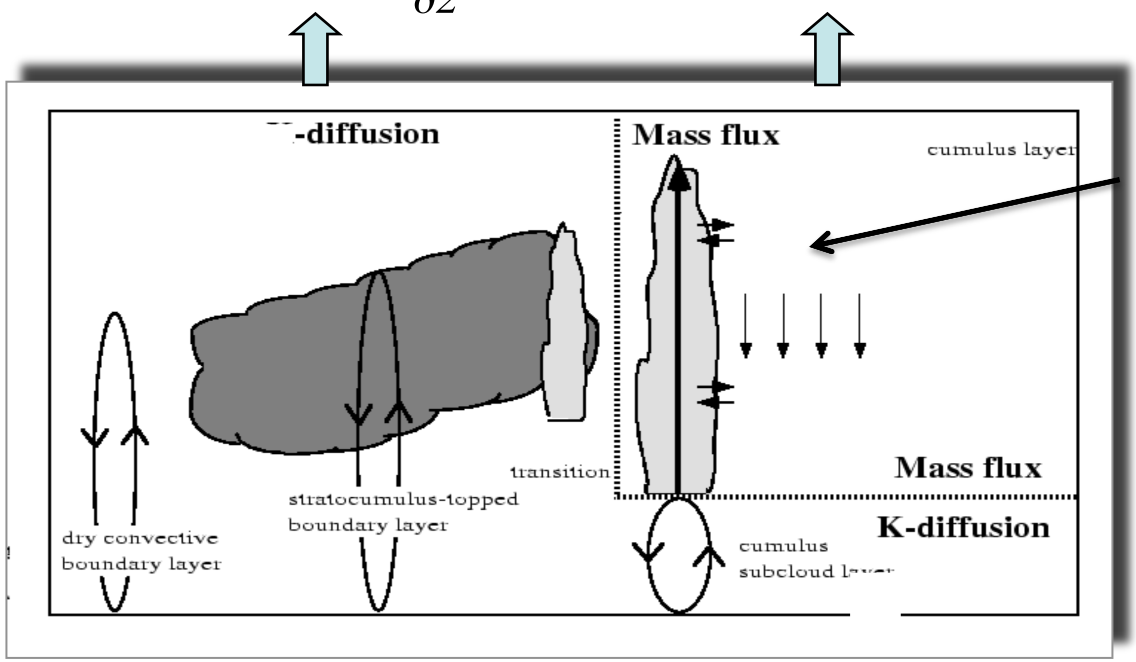
Modular vs. unified parameterization approaches

Modular turbulence and cloud fraction parameterizations make artificial divisions, leading to inconsistencies, process discontinuities, possible double-counting:

- Layer turbulence vs. shallow Cu vs. deep Cu
- Stratiform vs. convective cloud

Unified parameterizations (EDMF, CLUBB, etc.) aim to improve model fidelity by avoiding these divisions. Is this a better approach?

$$\overline{w'\phi'} \cong -K\frac{\partial\overline{\phi}}{\partial z} \qquad \overline{w'\phi'} \cong M(\phi_u - \overline{\phi})$$



Pros and cons of unified parameterizations

Promises:

- Internally consistent turbulence, cloud, precipitation
- Less artificial closure assumptions (e. g. on Cu mass flux)
- CLUBB and other HOC are more defensible in ‘grey zone’ of partly resolved Cu or turbulence.

Challenges:

- Still an oversimplified subgrid representation with many buried assumptions (lengthscales, tuning parameters, vertical overlap assumptions)
- Accurate, efficient numerical implementation?
- Philosophically, deep convection should be included, but it breaks assumptions underlying most unified schemes.

Stochastic parameterization

- Classical goal of parameterizations:

  A parameterization suite should provide **the ensemble mean** (i. e. an average of a realistic PDF) physics tendencies that are consistent with the given resolved-scale fields.

- A formulational goal of stochastic parameterization, consistent with use of an ensemble forecasting system:

  In an ideal world, a parameterization suite should provide **a random draw** from a realistic PDF of the physics tendencies that is consistent with the given resolved-scale fields.

Stochastic parameterization in reality

- In reality, even ideal stochastic parameterization is unlikely to produce nearly enough ensemble spread, due to grid scale smoothing, artificial scale separation, etc.
- Practical approaches (e. g. the ECMWF stochastic multiplier approach) have been useful but are ad hoc.
- The response of moist physics parameterization tendencies to small changes in large-scale forcing is often very jerky and nonlinear, inducing a poorly controlled quasi-stochastic aspect to the model response.

Addressing interaction problems

- Awareness – don't assume a combination of good parameterizations will give equally good results.
- Code transparency and documentation speed up detective work and sensitivity tests.
- Testing the system over a range of dz and dt (not just dx), using both single column tests and 3D runs. Discretization and process splitting errors can be hidden elephants.
- Use well observed globally-available diagnostics relevant to the outstanding problem the parameterization changes are meant to address, while at the same time checking standard performance metrics. Even a single one-day forecast can isolate important errors. Data assimilation (e.g. initial observational increments) should be used as part of the development process.

Research Issues

- Is sequential splitting an optimal approach? Or should we calculate and apply all moist and surface exchange processes on the same state?
- How do we choose the right vertical resolution for a given horizontal resolution?
- How strongly should we insist that parameterization systems perform smoothly across a range of vertical resolutions and time steps?
- Should we make parameterizations of subgrid heterogeneity simpler (as in CRMs) as global model resolution decreases?
- What is the appropriate role of stochastic parameterization in a large-scale forecasting system?

S12: Well-mixed Sc -SCAM5

Steady, diurnally average forcing
A near-saturated grid layer sits atop the well-mixed Sc layer.
Radiation-turbulence-entrainment feedback causes it to flip between cloudy and clear.